Filtering

A filter is a circuit that can pass (or amplify) certain frequencies while attenuating others. Therefore, filters can extract important frequencies from signals that also contain unwanted or irrelevant frequencies.

Signal Filters

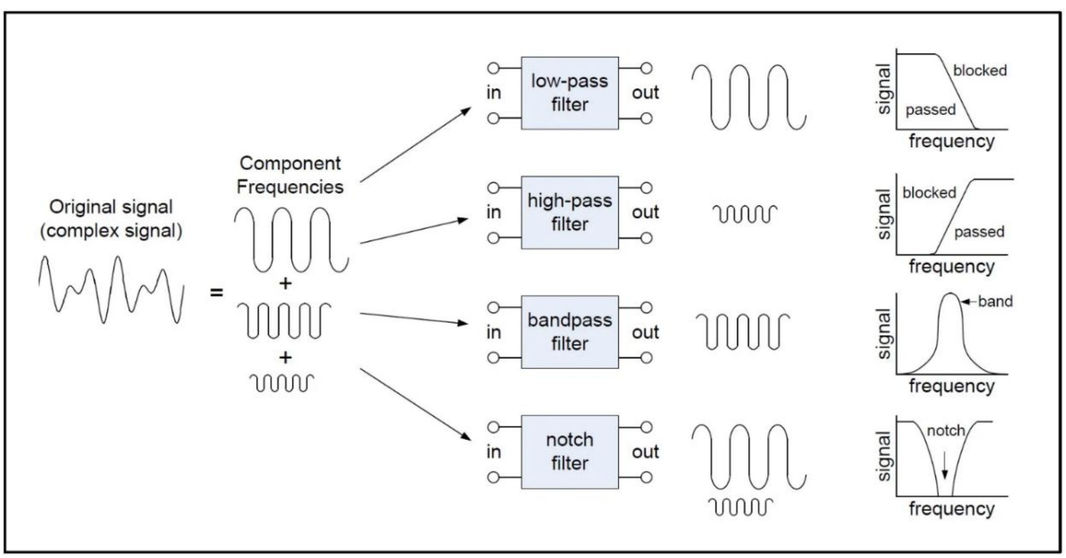
A signal filter is an electronic device or circuit designed to extract desired frequency components from a signal while suppressing or eliminating unwanted frequency components. They are widely used in communication systems, audio processing, image processing, and biomedical signal processing. There are many ways to design and implement signal filters, including analog and digital filters. Analog filters typically use resistors, capacitors, and inductors, while digital filters use digital signal processing techniques and software algorithms to achieve filtering.

Types of Filtering

- Hardware Filtering: Implemented directly in the circuit, with no computational delay.
- Software Filtering: Uses algorithms and code for filtering, offering flexibility and suitability for complex signal processing. However, it requires microcontroller resources.

Filter Classifications (Based on Frequency)

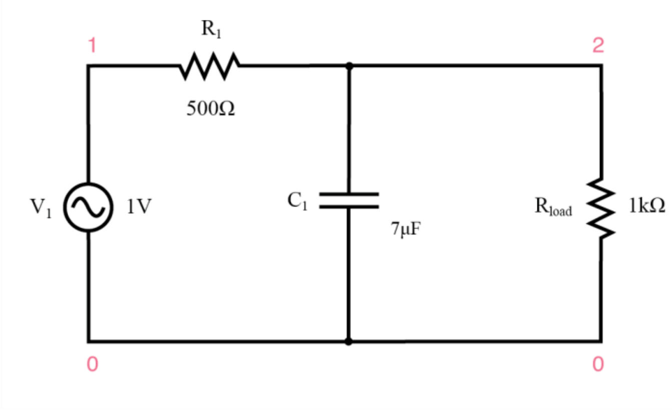
- Low-pass filter (LPF)
- High-pass filter (HPF)
- Band-pass filter (BPF)
- Band-stop filter (BSF)



Low-pass Filter (LPF)

A low-pass filter is a circuit that allows low-frequency signals to pass through while attenuating high-frequency signals. There are two basic types of circuits that can achieve this, each with many variations: capacitive low-pass filters and inductive low-pass filters.

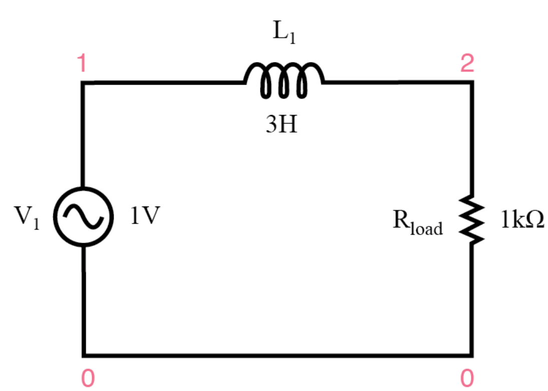
Capacitive Low-pass Filter



The impedance of a capacitor decreases with increasing frequency. This low impedance, in parallel with the load resistor, tends to short-circuit high-frequency signals, causing most of the voltage to drop across the series resistor.

Working Principle:A low-pass filter mainly relies on capacitors and resistors. The capacitor's impedance is small for high-frequency signals, meaning they are short-circuited at the capacitor and prevented from passing through the filter. For low-frequency signals, the impedance is high, allowing them to pass through smoothly. **High frequencies are short-circuited (X) and prevented from passing, while low frequencies pass through smoothly.**

Inductive Low-pass Filter



The impedance of an inductor is high for high-frequency signals, preventing them from passing and thus suppressing high-frequency signals. For low-frequency signals, the impedance is low, allowing most of the signal to pass through the resistor to the output.

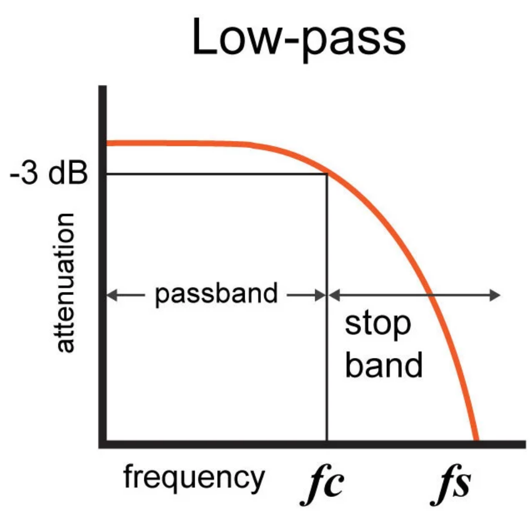
Cutoff Frequency

The rated value of a low-pass filter includes a specific cutoff frequency, the frequency at which the output voltage drops to 70.7% of the input voltage. Frequencies higher than this cutoff frequency are filtered out. By knowing the cutoff frequency, we can determine which frequencies can pass through and which will be blocked.

For RC circuits, the cutoff frequency: $\boldsymbol{Fc = \frac{1}{2*\pi*R*C}}$

For RL circuits, the cutoff frequency: $\boldsymbol{Fc = \frac{R}{2*\pi*L}}$

Relationship Between Circuit Diagram and Amplitude Response:



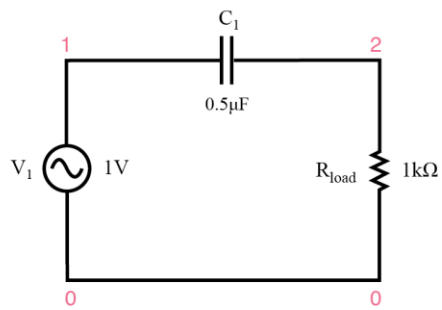
The time constant τ in filter design represents the dynamic response characteristics of the circuit. For RC circuits, τ = RC; for RL circuits, τ = L/R. The time constant determines the response speed of the circuit. In an RC low-pass filter, a larger τ means more significant attenuation of high-frequency signals and a slower response speed. The amplitude response (A(f)) shows that as frequency increases, the amplitude of the output signal gradually decreases. The frequency at 1/ (2*π* τ) marks the beginning of a significant drop, with higher frequencies having lower chances of passing through.

High-pass Filter (HPF)

A high-pass filter allows high-frequency signals to pass through easily while attenuating low-frequency signals.

RC Circuit High-pass Filter

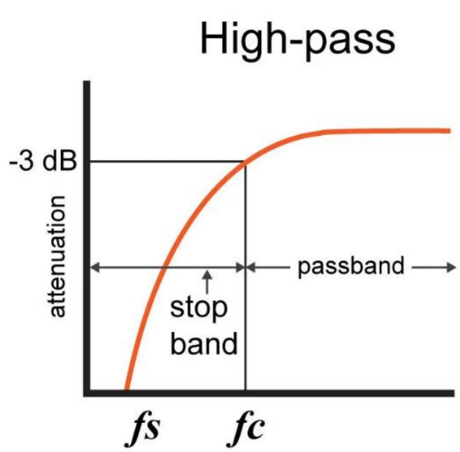
- The capacitor has high impedance for low-frequency signals, preventing them from passing and thus suppressing low-frequency signals.
- The capacitor has low impedance for high-frequency signals, allowing them to pass through the resistor to the output.

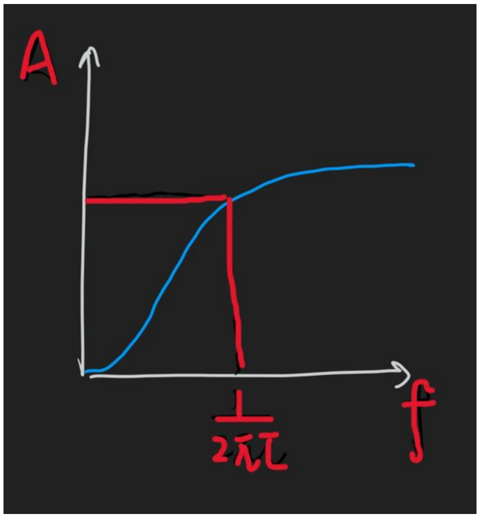


RL Circuit High-pass Filter

- The inductor has low impedance for low-frequency signals, allowing them to pass and be "short-circuited" to ground, thus suppressing low-frequency signals.
- The inductor has high impedance for high-frequency signals, preventing them from passing, and allowing them to pass through the resistor to the output.

Relationship Between Circuit Diagram and Amplitude Response:

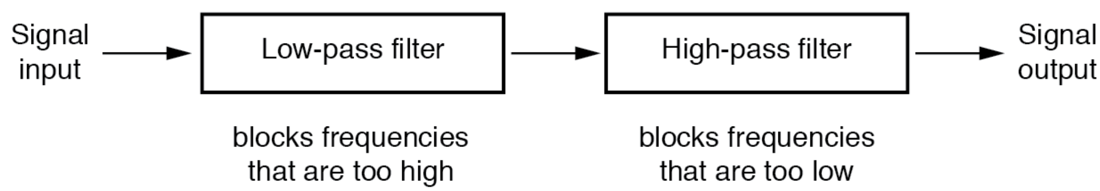




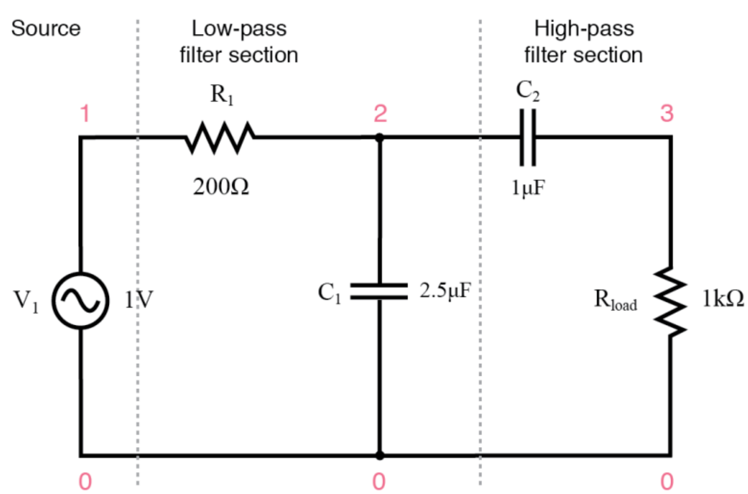
The curve shows that as the frequency increases, the gain of the filter also increases, corresponding to the high-pass filter's characteristic of attenuating low-frequency signals and allowing high-frequency signals to pass through.

Band-pass Filter (BPF)

A band-pass filter combines low-pass and high-pass filters in a single circuit, allowing only signals within a specific frequency range (the passband) to pass through while attenuating signals below and above this range.

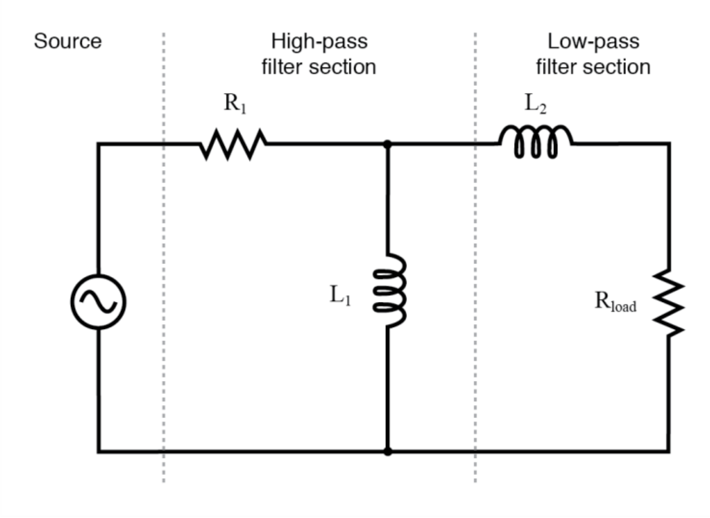


Capacitive Band-pass Filter



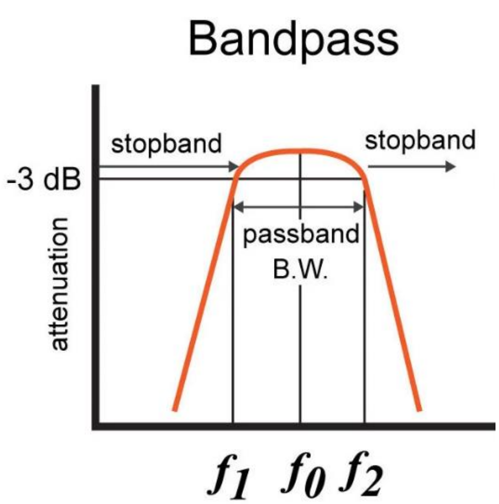
An RC band-pass filter circuit includes a series low-pass filter (capacitor C1 and resistor R1) and a high-pass filter (resistor R2 and capacitor C2). **The input signal passes through the low-pass filter first, then the high-pass filter, allowing only intermediate frequencies to pass.**

Inductive Band-pass Filter



The high-pass filter part includes resistor R1 and inductor L1, while the low-pass filter part includes inductor L2 and load resistor R_load. The input signal passes through the high-pass filter first, then the low-pass filter.

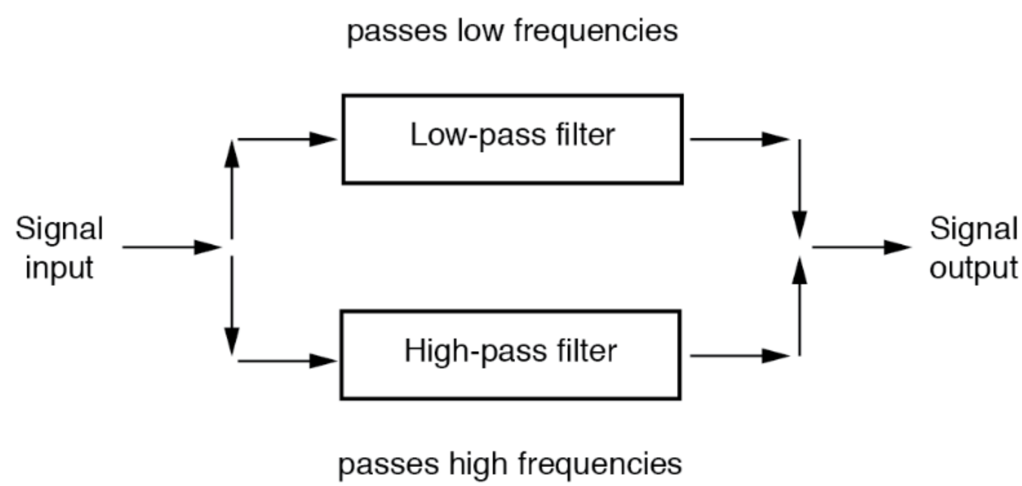
Amplitude Response of BPF



Shows that the filter allows signals within a specific frequency range to pass while attenuating signals outside this range. **The amplitude response graph indicates that signals below the lower cutoff frequency f1 and above the upper cutoff frequency f2 are attenuated.**

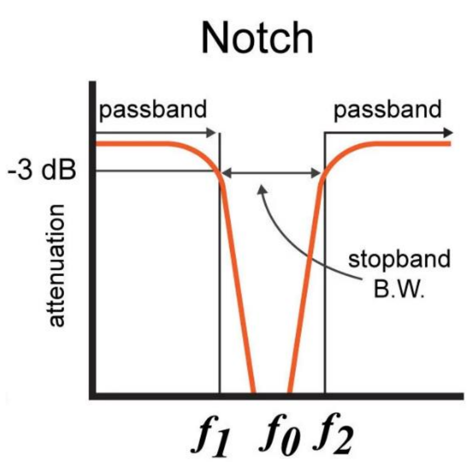
Band-stop Filter (BSF)

A band-stop filter, also known as a notch filter or band-reject filter, is an electronic filter that blocks signals within a specific frequency range while allowing signals outside this range to pass. **It is usually composed of a parallel combination of a low-pass and a high-pass filter.**



Characteristics of BSF:

- Center Frequency f_0: The center frequency of the stopband.
- Bandwidth (BW): The width of the frequency range that is blocked.
- Lower Cutoff Frequency f1: The lowest frequency at which the filter starts to block signals.
- Upper Cutoff Frequency f2: The highest frequency at which the filter stops blocking signals.



Design Parameters for BSF:

- Center Frequency f_0: Chosen based on the application to block specific frequencies.
- Bandwidth (BW): Determines the width of the frequency band to be blocked.
- Q-factor (Q): Defined as the ratio of the center frequency to the bandwidth, determining the filter's selectivity.
- Formula: **$Q = f0 / BW$**

Reference:

An Introduction to Filters - Technical Articles (allaboutcircuits.com)

Low-pass Filters | Filters | Electronics Textbook (allaboutcircuits.com)

High-pass Filters | Filters | Electronics Textbook (allaboutcircuits.com)

Band-pass Filters | Filters | Electronics Textbook (allaboutcircuits.com)

Band-stop Filters | Filters | Electronics Textbook (allaboutcircuits.com)